15

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B23K 31/02	A1	(11) International Publication Number: WO 96/37333 (43) International Publication Date: 28 November 1996 (28.11.96)

(21) International Application Number: PCT/US96/08274

(22) International Filing Date: 28 May 1996 (28.05.96)

(30) Priority Data:

08/452,255	26 May 1995 (26.05.95)	US
08/526,246	21 September 1995 (21.09.95)	US
08/533,584	18 October 1995 (18.10.95)	US
08/554,902	9 November 1995 (09.11.95)	US
PCT/US95/14909	13 November 1995 (13.11.95)	US
08/558,332	15 November 1995 (15.11.95)	US
60/012,878	5 March 1996 (05.03.96)	US

(71) Applicant (*for all designated States except US*): FORMFACTOR, INC. [US/US]; 2130 Research Drive, Livermore, CA 94550 (US).

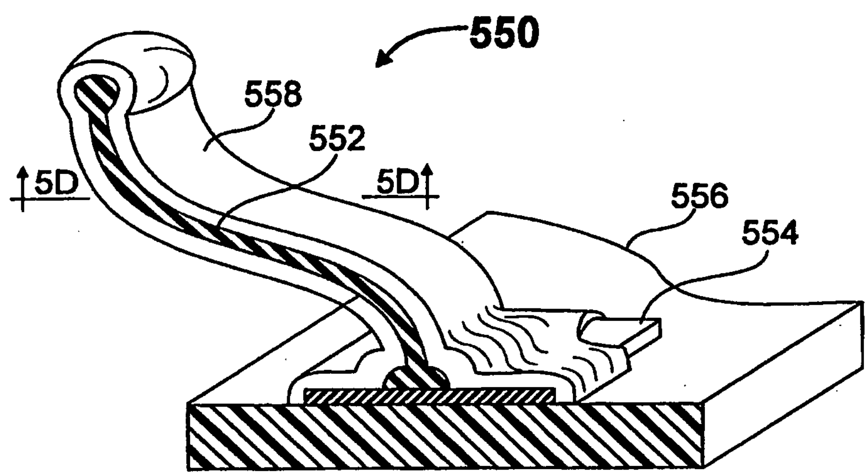
(72) Inventors; and
(75) Inventors/Applicants (*for US only*): KHANDROS, Igor, Y. [US/US]; 25 Haciendas Road, Orinda, CA 94563 (US). DOZIER, Thomas, H. [US/US]; 2806 Lakeside Lane, Carrolton, TX 75006 (US). ELDRIDGE, Benjamin, N. [US/US]; 901 Ocho Rios Drive, Danville, CA 94523 (US). GARY, W., Grube [US/US]; 6807 Singletree Court, Pleasanton, CA 94588 (US). GAETAN, L., Mathieu [CA/US]; Apartment 203, 7980 Fall Creek Road, Dublin, CA 94568 (US).

(74) Agent: LINDEN, Gerald, E.; Suite 300, 2716 South Chickasaw Trail, Orlando, FL 32829 (US).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: RIBBON-LIKE CORE INTERCONNECTION ELEMENTS



(57) Abstract

Interconnection elements (550) for electronic components (556), exhibiting desirable mechanical characteristics (such as resiliency), for making pressure contact(s) are formed by shaping a ribbon-like core element (552) of a soft material (such as gold or soft copper) to have a springable shape (including cantilever beam, S-shape, U-shape), and overcoating the shaped core element with a hard material (558) such as nickel and it alloys, to impart a desired spring (resilient) characteristic to the resulting composite interconnection element (550). A final overcoat of a material (220) having superior electrical qualities (e.g., electrical conductivity and/or solderability) may be applied to the composite interconnection element (200). The resulting interconnection elements (500, 550) may be mounted to a variety of electronic components.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

RIBBON-LIKE-CORE INTERCONNECTION ELEMENTS

TECHNICAL FIELD OF THE INVENTION

The invention relates to making interconnections between electronic components, especially microelectronic components and, more particularly, to interconnection elements exhibiting resiliency, for making pressure contacts, methods of making the interconnection elements, and applications for same.

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation-in-part of commonly-owned, copending U.S. Patent Application No. **08/452,255** (hereinafter "PARENT CASE") filed 26 May 95 and its counterpart PCT patent application number PCT/US95/14909 filed 13 NOV 95, both of which are continuations-in-part of commonly-owned, copending U.S. Patent Application No. **08/340,144** filed 15 Nov 94 and its counterpart PCT patent application number PCT/US94/13373 filed 16 Nov 94 (published 26 May 95 as WO 95/14314), both of which are continuations-in-part of commonly-owned, copending U.S. Patent Application No. 08/152,812 filed 16 Nov 93 (now **USP 5,476,211**, 19 Dec 95), all of which are incorporated by reference herein.

This patent application is also a continuation-in-part of the following commonly-owned, copending U.S. Patent Application Nos.:

08/526,246 filed 21 SEP 95 (PCT/US95/14843, 13 NOV 95);
08/533,584 filed 18 OCT 95 (PCT/US95/14842, 13 NOV 95);
08/554,902 filed 09 NOV 95 (PCT/US95/14844, 13 NOV 95);
08/558,332 filed 15 NOV 95 (PCT/US95/14885, 15 NOV 95);
08/573,945 filed 18 DEC 95;
08/584,981 filed 11 JAN 96;
08/602,179 filed 15 FEB 96;
60/012,027 filed 21 FEB 96;
60/012,040 filed 22 FEB 96;
60/012,878 filed 05 MAR 96;
60/013,247 filed 11 MAR 96; and
60/005,189 filed 17 MAY 96

all of which are continuations-in-part of the aforementioned PARENT CASE, and all of which are incorporated by reference herein.

BACKGROUND OF THE INVENTION

Electronic components, particularly microelectronic components such as semiconductor devices (chips), often have a plurality of terminals (also referred to as bond pads, electrodes, or conductive areas). In order to assemble such devices into a useful system (or subsystem), a number of individual devices must be electrically interconnected with one another, typically through the intermediary of a printed circuit (or wiring) board (PCB, PWB).

Semiconductor devices are typically disposed within a semiconductor package having a plurality of external connections in the form of pins, pads, leads, solder balls, and the like. Many types of semiconductor packages are known, and techniques for connecting the semiconductor device within the package include bond wires, tape-automated bonding (TAB) and the like. In some cases, a semiconductor device is provided with raised bump contacts, and is connected by flip-chip techniques onto another electronic component.

Generally, interconnections between electronic components can be classified into the two broad categories of "relatively permanent" and "readily demountable".

An example of a "relatively permanent" connection is a solder joint. Once two electronic components are soldered to one another, a process of unsoldering must be used to separate the components. A wire bond is another example of a "relatively permanent" connection.

An example of a "readily demountable" connection is rigid pins of one electronic component being received by resilient socket elements of another electronic component. The socket elements exert a contact force (pressure) on the pins in an

amount sufficient to ensure a reliable electrical connection therebetween. Interconnection elements intended to make pressure contact with an electronic component are referred to herein as "springs" or "spring elements" or "spring contacts".

Prior art techniques for making spring elements generally involve stamping (punching) or etching a "monolithic" spring material, such as phosphor bronze or beryllium copper or steel or a nickel-iron-cobalt (e.g., kovar) alloy, to form individual spring elements, shaping the spring elements to have a spring shape (e.g., arcuate, etc.), plating the spring elements with a good contact material (e.g., a noble metal such as gold, which will exhibit low contact resistance when contacting a like material), and molding a plurality of such shaped, plated spring elements into a linear, a peripheral or an array pattern. When plating gold onto the aforementioned materials, sometimes a thin (for example, 30-50 microinches, barrier layer of nickel is appropriate.

Generally, a certain minimum contact force is desired to effect reliable pressure contact to electronic components (e.g., to terminals on electronic components). For example, a contact (load) force of approximately 15 grams (including as little as 2 grams or less and as much as 150 grams or more, per contact) may be desired to ensure that a reliable electrical connection is made to a terminal of an electronic component which may be contaminated with films on its surface, or which has corrosion or oxidation products on its surface. The minimum contact force required of each spring element typically demands either that the yield strength of the spring material or that the size of the spring element are increased. However, generally, the higher the yield strength of a material, the more difficult it will be to work with (e.g., punch, bend, etc.). And the desire to make springs smaller essentially rules out making them larger in cross-section.

Another problem associated with mounting springs on electronic components is largely mechanical in nature. In cases where a spring is mounted at one end to a substrate (which, for purposes of this proposition is considered to be an immovable object), and is required to react forces applied at its free end, the "weak link" (weakest point, in service) will often be the point at which the spring is attached (e.g., the base of the spring is bonded) to the substrate (e.g., terminal of an electronic component).

Another subtle problem associated with interconnection elements, including spring contacts, is that, often, the terminals of an electronic component are not perfectly coplanar. Interconnection elements lacking in some mechanism incorporated therewith for accommodating these "tolerances" (gross non-planarities) will be hard pressed to make consistent contact pressure contact with the terminals of the electronic component.

The following U.S. Patents are cited as being of interest: 5,386,344; 5,336,380; 5,317,479; 5,086,337; 5,067,007; 4,989,069; 4,893,172; 4,793,814; 4,777,564; 4,764,848; 4,667,219; 4,642,889; 4,330,165; 4,295,700; 4,067,104; 3,795,037; 3,616,532; and 3,509,270.

BRIEF DESCRIPTION (SUMMARY) OF THE INVENTION

It is therefore an object of the invention to provide a technique for fabricating interconnection elements for electronic components, especially microelectronic components.

It is another object of the invention to provide resilient contact structures (interconnection elements) that are suitable for making pressure contact to electronic components.

It is another object of the invention to provide a technique for securely anchoring interconnection elements to electronic components.

It is another object of the invention to provide a technique for manufacturing interconnection elements having controlled impedance.

According to the invention, techniques are disclosed for fabricating interconnection elements, particularly spring elements, and for mounting the interconnection elements to electronic components. The disclosed techniques overcome problems associated with making spring elements of extremely small size, yet which are capable of exerting contact forces of sufficient magnitude to ensure reliable interconnections. The disclosed techniques also overcome problems associated with mounting springs directly on various electronic components, such as semiconductor devices.

According to the invention, a "composite" interconnection element is fabricated by mounting a ribbon-like elongate element ("core element") to an electronic component, shaping the core element to have a spring shape, and overcoating the core element to enhance the physical (e.g., spring) characteristics of the resulting composite interconnection element and/or to securely

anchor the resulting composite interconnection element to the electronic component.

As used herein, the terms "ribbon" and "ribbon-like", refer to elongate elements having a non-circular cross-section, with a one cross (transverse) dimension being at least twice (including at least three, four or five times) as large as another cross dimension. For example, an elongate element having a rectangular cross-section, said rectangle having a base dimension which is at least twice the height dimension (or vice-versa).

The use of the term "composite", throughout the description set forth herein, is consistent with a 'generic' meaning of the term (e.g., formed of two or more elements), and is not to be confused with any usage of the term "composite" in other fields of endeavor, for example, as it may be applied to materials such as glass, carbon or other fibers supported in a matrix of resin or the like.

As used herein, the term "spring shape" refers to virtually any shape of an elongate element which will exhibit elastic (restorative) movement of an end (tip) of the elongate element with respect to a force applied to the tip. This includes elongate elements shaped to have one or more bends, as well as substantially straight elongate elements.

As used herein, the terms "contact area", "terminal", "pad", and the like refer to any conductive area on any electronic component to which an interconnection element is mounted or makes contact.

Alternatively, the core element is shaped prior to mounting to an electronic component.

Alternatively, the core element is mounted to or is a part of a sacrificial substrate which is not an electronic component. The sacrificial substrate is removed after shaping, and either before or after overcoating the core element. According to an aspect of the invention, tips having various rough surface finishes can be disposed at the contact ends of the interconnection elements. (See also Figures 11A-11F of the PARENT CASE.)

In an embodiment of the invention, the core is a "soft" material having a relatively low yield strength, and is overcoated with a "hard" material having a relatively high yield strength. For example, a soft material such as a gold wire is attached (e.g., by wire bonding) to a terminal of an electronic component, and is overcoated (e.g., by electrochemical plating) with a hard material such nickel and its alloys.

Vis-a-vis overcoating the core element, single and multi-layer overcoatings, "rough" overcoatings having microprotrusions (see also Figures 5C and 5D of the PARENT CASE), and overcoatings extending the entire length of or only a portion of the length of the core element, are described. In the latter case, the tip of the core element may suitably be exposed for making contact to an electronic component (see also Figure 5B of the PARENT CASE).

Generally, throughout the description set forth herein, the term "plating" is used as exemplary of a number of techniques for overcoating the core. It is within the scope of this invention that the core can be overcoated by any suitable technique including, but not limited to: various processes involving deposition of materials out of aqueous solutions; electrolytic plating; electroless plating; chemical vapor deposition (CVD); physical vapor deposition (PVD); processes causing the deposition of materials through induced

disintegration of liquid or solid precursors; and the like, all of these techniques for depositing materials being generally well known.

Generally, for overcoating the core element with a metallic material such as nickel, electrochemical processes are preferred, especially electrolytic plating.

In another embodiment of the invention, the core is an elongate element of a "hard" material, inherently suitable to functioning as a spring element, and is mounted at one end to a terminal of an electronic component. The core, and at least an adjacent area of the terminal, is overcoated with a material which will enhance anchoring the core to the terminal. In this manner, it is not necessary that the core be well-mounted to the terminal prior to overcoating, and processes which are less potentially damaging to the electronic component may be employed to "tack" the core in place for subsequent overcoating. These "friendly" processes include soldering, gluing, and piercing an end of the hard core into a soft portion of the terminal. Representative materials, both for the core element and for the overcoatings, are disclosed.

In the main hereinafter, techniques involving beginning with a relatively soft (low yield strength) core element, which is generally of very small dimension (e.g., 2.0 mil or less) are described. Soft materials, such as gold, which attach easily to the metallization (e.g., aluminum) of semiconductor devices, generally lack sufficient resiliency to function as springs. (Such soft, metallic materials exhibit primarily plastic, rather than elastic deformation.) Other soft materials which may attach easily to semiconductor devices and possess appropriate resiliency are often electrically non-conductive, as in the case of most elastomeric materials. In either case, desired structural and electrical characteristics can be imparted to the

resulting composite interconnection element by the overcoating applied over the core. The resulting composite interconnection element can be made very small, yet can exhibit appropriate contact forces. Moreover, a plurality of such composite interconnection elements can be arranged at a fine pitch (e.g., 10 mils), even though the have a length (e.g., 100 mils) which is much greater than the distance to a neighboring composite interconnection element (the distance between neighboring interconnection elements being termed "pitch").

It is within the scope of this invention that composite interconnection elements can be fabricated on a microminiature scale, for example as "microsprings" for connectors and sockets, having cross-sectional dimensions on the order of twenty-five microns (μm), or less. This ability to manufacture reliable interconnection having dimensions measured in microns, rather than mils, squarely addresses the evolving needs of existing interconnection technology and future area array technology.

The composite interconnection elements of the present invention exhibit superior electrical characteristics, including electrical conductivity, solderability and low contact resistance. In many cases, deflection of the interconnection element in response to applied contact forces results in a "wiping" contact, which helps ensure that a reliable contact is made.

An additional advantage of the present invention is that connections made with the interconnection elements of the present invention are readily demountable. Soldering, to effect the interconnection to a terminal of an electronic component is optional, but is generally not preferred at a system level.

According to an aspect of the invention, techniques are described for making interconnection elements having controlled

impedance. These techniques generally involve coating (e.g., electrophoretically) a core element or an entire composite interconnection element with a dielectric material (insulating layer), and overcoating the dielectric material with an outer layer of a conductive material. By grounding the outer conductive material layer, the resulting interconnection element can effectively be shielded, and its impedance can readily be controlled. (See also Figure 10K of the PARENT CASE.)

According to an aspect of the invention, interconnection elements can be pre-fabricated as individual units, for later attachment to electronic components. Various techniques for accomplishing this objective are set forth herein. Although not specifically covered in this document, it is deemed to be relatively straightforward to fabricate a machine that will handle the mounting of a plurality of individual interconnection elements to a substrate or, alternatively, suspending a plurality of individual interconnection elements in an elastomer, or on a support substrate.

It should clearly be understood that the composite interconnection element of the present invention differs dramatically from interconnection elements of the prior art which have been coated to enhance their electrical conductivity characteristics or to enhance their resistance to corrosion.

The overcoating of the present invention is specifically intended to substantially enhance anchoring of the interconnection element to a terminal of an electronic component and/or to impart desired resilient characteristics to the resulting composite interconnection element. Stresses (contact forces) are directed to portions of the interconnection elements which are specifically intended to absorb the stresses.

One advantage of the invention is that the processes

described herein are well-suited to "pre-fabricating" interconnection elements, particularly resilient interconnection elements, such as on a sacrificial member, then later mounting the interconnection elements to an electronic component. In contrast to fabricating the interconnection elements directly on the electronic component, this allows for reduced cycle time in processing the electronic components. Additionally, yield issues which may be associated with the fabrication of the interconnection elements are thus disassociated from the electronic component. For example, it would be disingenuous for an otherwise perfectly good, relatively expensive integrated circuit device to be ruined by glitches in the process of fabricating interconnection elements mounted thereto. The mounting of pre-fabricated interconnection elements to electronic components is relatively straightforward, as is evident from the description set forth hereinbelow.

It should also be appreciated that the present invention provides essentially a new technique for making spring structures. Generally, the operative structure of the resulting spring is a product of plating, rather than of bending and shaping. This opens the door to using a wide variety of materials to establish the spring shape, and a variety of "friendly" processes for attaching the "falsework" of the core to electronic components. The overcoating functions as a "superstructure" over the "falsework" of the core, both of which terms have their origins in the field of civil engineering.

Other objects, features and advantages of the invention will become apparent in light of the following description thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made in detail to preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Although the invention will be described in the context of these preferred embodiments, it should be understood that it is not intended to limit the spirit and scope of the invention to these particular embodiments.

In the side views presented herein, often portions of the side view are presented in cross-section, for illustrative clarity. For example, in many of the views, the wire stem (core element) is shown full, as a solid bold line, while the overcoat is shown in true cross-section (often without crosshatching).

In the figures presented herein, the size of certain elements are often exaggerated (not to scale, vis-a-vis other elements in the figure), for illustrative clarity.

Figure 1A is a cross-sectional view of a longitudinal portion, including one end, of an interconnection element, according to an embodiment of the invention.

Figure 1B is a cross-sectional view of a longitudinal portion, including one end, of an interconnection element, according to another embodiment of the invention.

Figure 1C is a cross-sectional view of a longitudinal portion, including one end of an interconnection element, according to another embodiment of the invention.

Figure 1D is a cross-sectional view of a longitudinal portion, including one end of an interconnection element, according to another embodiment of the invention.

Figure 1E is a cross-sectional view of a longitudinal portion, including one end of an interconnection element, according to another embodiment of the invention.

Figure 2A is a cross-sectional view of an interconnection element mounted to a terminal of an electronic component and having a multi-layered shell, according to the invention.

Figure 2B is a cross-sectional view of an interconnection element having a multi-layered shell, wherein an intermediate layer is of a dielectric material, according to the invention.

Figure 2C is a perspective view of a plurality of interconnection elements mounted to an electronic component (e.g., a probe card insert), according to the invention.

Figure 2D is a cross-sectional view of an exemplary first step of a technique for manufacturing interconnection elements, according to the invention.

Figure 2E is a cross-sectional view of an exemplary further step of the technique of **Figure 2D** for manufacturing interconnection elements, according to the invention.

Figure 2F is a cross-sectional view of an exemplary further step of the technique of **Figure 2E** for manufacturing interconnection elements, according to the invention.

Figure 2G is a cross-sectional view of an exemplary plurality of individual interconnection elements fabricated according to the technique of **Figures 2D-2F**, according to the invention.

Figure 2H is a cross-sectional view of an exemplary plurality of interconnection elements fabricated according to

the technique of **Figures 2D-2F**, and associated in a prescribed spatial relationship with one another, according to the invention.

Figure 2I is a cross-sectional view of an alternate embodiment for manufacturing interconnection elements, showing a one end of one element, according to the invention.

Figure 3 is a cross-sectional view of an embodiment of an interposer, illustrating the concept that a single resilient (pressure) connection may be effected by a pair of composite interconnection elements, according to the invention.

Figure 4 is a cross-sectional view of a composite interconnection element extending free-standing from a terminal of an electronic component, according to the invention, and is similar in many respects to the illustrations of **Figures 1E and 2A**.

Figure 4A is a cross-sectional view of the composite interconnection element of **Figure 4**, illustrating that the wire stem has a circular cross-section, according to the invention.

Figure 4B is a cross-sectional view of a pair of composite interconnection elements (compare **Figure 3**), illustrating that each of the two wire stems has a circular cross-section, according to the invention.

Figure 5 is a perspective view of a ribbon-like core element mounted to a terminal on an electronic component, according to the invention.

Figure 5A is a cross-sectional view of a ribbon-like core element which has been ball-bonded to a terminal on an electronic component, according to the invention.

Figure 5B is a cross-sectional view of the ribbon-like core element of **Figure 5A**, after overcoating, according to the invention.

Figure 5C is a partial perspective view of a composite interconnection element formed with a ribbon-like core, according to the invention.

Figure 5D is a cross-sectional view of the composite interconnection element of **Figure 5C**.

Figure 5E is a cross-sectional view of a composite interconnection element comprising 5 (five) individual composite interconnection elements, which may be formed according to the techniques set forth herein.

Figure 6A is a side view of a capillary for a wirebonder, according to the invention.

Figure 6B is an end view of the capillary of **Figure 6A**, showing the tip of the capillary, according to the invention.

Figure 7A is a perspective view of wirebonding apparatus, including an embodiment of an external shaping tool, according to an aspect of the invention.

Figures 7B and 7C are side views of a method of shaping an elongate element (e.g., wire) with the shaping tool of **Figure 7A**, according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The disclosure of the aforementioned U.S. Patent Application No. 08/452,255, filed 5/26/95 ("PARENT CASE") is incorporated by reference herein. This patent application summarizes several of the techniques disclosed therein.

An important aspect of the present invention is that a composite interconnection element can be formed by starting with a core (which may be mounted to a terminal of an electronic component), then overcoating the core with an appropriate material to: (1) establish the mechanical properties of the resulting "composite" interconnection element; and/or (2) when the interconnection element is mounted to a terminal of an electronic component, securely anchor the interconnection element to the terminal. In this manner, a resilient interconnection element (spring element) can be fabricated, starting with a core of a soft material which is readily shaped into a springable shape and which is readily attached to even the most fragile of electronic components. In light of prior art techniques of forming spring elements from hard materials, is not readily apparent, and is arguably counter-intuitive, that soft materials can form the basis of spring elements. Such a "composite" interconnection element is generally the preferred form of resilient contact structure for use in the embodiments of the present invention.

Figures 1A, 1B, 1C and 1D illustrate, in a general manner, various shapes for composite interconnection elements, according to the present invention.

In the main, hereinafter, composite interconnection elements which exhibit resiliency are described. However, it should be understood that non-resilient composite interconnection elements fall within the scope of the invention.

Further, in the main hereinafter, composite interconnection elements that have a soft (readily shaped, and amenable to affixing by friendly processes to electronic components) core, overcoated by hard (springy) materials are described. It is, however, within the scope of the invention that the core can be a hard material -the overcoat serving primarily to securely anchor the interconnection element to a terminal of an electronic component.

In **Figure 1A**, an electrical interconnection element 110 includes a core 112 of a "soft" material (e.g., a material having a yield strength of less than 40,000 psi), and a shell (overcoat) 114 of a "hard" material (e.g., a material having a yield strength of greater than 80,000 psi). The core 112 is an elongate element shaped (configured) as a substantially straight cantilever beam, and may be a wire having a diameter of 0.0005-0.0030 inches (0.001 inch = 1 mil ≈ 25 microns (μm)). The shell 114 is applied over the already-shaped core 112 by any suitable process, such as by a suitable plating process (e.g., by electrochemical plating).

Figure 1A illustrates what is perhaps the simplest of spring shapes for an interconnection element of the present invention - namely, a straight cantilever beam oriented at an angle to a force "*F*" applied at its tip 110b. When such a force is applied by a terminal of an electronic component to which the interconnection element is making a pressure contact, the downward (as viewed) deflection of the tip will evidently result in the tip moving across the terminal, in a "wiping" motion. Such a wiping contact ensures a reliable contact being made between the interconnection element and the contacted terminal of the electronic component.

By virtue of its "hardness", and by controlling its

thickness (0.00025-0.00500 inches), the shell 114 imparts a desired resiliency to the overall interconnection element 110. In this manner, a resilient interconnection between electronic components (not shown) can be effected between the two ends 110a and 110b of the interconnection element 110. (In **Figure 1A**, the reference numeral 110a indicates an end portion of the interconnection element 110, and the actual end opposite the end 110b is not shown.) In contacting a terminal of an electronic component, the interconnection element 110 would be subjected to a contact force (pressure), as indicated by the arrow labelled "***F***".

It is generally preferred that the thickness of the overcoat (whether a single layer or a multi-layer overcoat) be thicker than the diameter of the wire being overcoated. Given the fact that the overall thickness of the resulting contact structure is the sum of the thickness of the core plus twice the thickness of the overcoat, an overcoat having the same thickness as the core (e.g., 1 mil) will manifest itself, in aggregate, as having twice the thickness of the core.

The interconnection element (e.g., 110) will deflect in response to an applied contact force, said deflection (resiliency) being determined in part by the overall shape of the interconnection element, in part by the dominant (greater) yield strength of the overcoating material (versus that of the core), and in part by the thickness of the overcoating material.

As used herein, the terms "cantilever" and "cantilever beam" are used to indicate that an elongate structure (e.g., the overcoated core 112) is mounted (fixed) at one end, and the other end is free to move, typically in response to a force acting generally transverse to the longitudinal axis of the elongate element. No other specific or limiting meaning is intended to be conveyed or connoted by the use of these terms.

In **Figure 1B**, an electrical interconnection element 120 similarly includes a soft core 122 (compare 112) and a hard shell 124 (compare 114). In this example, the core 122 is shaped to have two bends, and thus may be considered to be S-shaped. As in the example of **Figure 1A**, in this manner, a resilient interconnection between electronic components (not shown) can be effected between the two ends 120a and 120b of the interconnection element 120. (In **Figure 1B**, reference numeral 120a indicates an end portion of the interconnection element 120, and the actual end opposite the end 120b is not shown.) In contacting a terminal of an electronic component, the interconnection element 120 would be subjected to a contact force (pressure), as indicated by the arrow labelled "*F*".

In **Figure 1C**, an electrical interconnection element 130 similarly includes a soft core 132 (compare 112) and a hard shell 134 (compare 114). In this example, the core 132 is shaped to have one bend, and may be considered to be U-shaped. As in the example of **Figure 1A**, in this manner, a resilient interconnection between electronic components (not shown) can be effected between the two ends 130a and 130b of the interconnection element 130. (In **Figure 1C**, the reference numeral 130a indicates an end portion of the interconnection element 130, and the actual end opposite the end 130b is not shown.) In contacting a terminal of an electronic component, the interconnection element 130 could be subjected to a contact force (pressure), as indicated by the arrow labelled "*F*". Alternatively, the interconnection element 130 could be employed to make contact at other than its end 130b, as indicated by the arrow labelled "*F'*".

Figure 1D illustrates another embodiment of a resilient interconnection element 140 having a soft core 142 and a hard shell 144. In this example, the interconnection element 140 is

essentially a simple cantilever (compare **Figure 1A**), with a curved tip 140b, subject to a contact force "*F*" acting transverse to its longitudinal axis.

Figure 1E illustrates another embodiment of a resilient interconnection element 150 having a soft core 152 and a hard shell 154. In this example, the interconnection element 150 is generally "C-shaped", preferably with a slightly curved tip 150b, and is suitable for making a pressure contact as indicated by the arrow labelled "*F*".

It should be understood that the soft core can readily be formed into any springable shape - in other words, a shape that will cause a resulting interconnection element to deflect resiliently in response to a force applied at its tip. For example, the core could be formed into a conventional coil shape. However, a coil shape would not be preferred, due to the overall length of the interconnection element and inductances (and the like) associated therewith and the adverse effect of same on circuitry operating at high frequencies (speeds).

The material of the shell, or at least one layer of a multi-layer shell (described hereinbelow) has a significantly higher yield strength than the material of the core. Therefore, the shell overshadows the core in establishing the mechanical characteristics (e.g., resiliency) of the resulting interconnection structure. Ratios of shell:core yield strengths are preferably at least 2:1, including at least 3:1 and at least 5:1, and may be as high as 10:1. It is also evident that the shell, or at least an outer layer of a multi-layer shell should be electrically conductive, notably in cases where the shell covers the end of the core. (The parent case, however, describes embodiments where the end of the core is exposed, in which case the core must be conductive.)

From an academic viewpoint, it is only necessary that the springing (spring shaped) portion of the resulting composite interconnection element be overcoated with the hard material. From this viewpoint, it is generally not essential that both of the two ends of the core be overcoated. As a practical matter, however, it is preferred to overcoat the entire core. Particular reasons for and advantages accruing to overcoating an end of the core which is anchored (attached) to an electronic component are discussed in greater detail hereinbelow.

Suitable materials for the core (112, 122, 132, 142) include, but are not limited to: gold, aluminum, copper, and their alloys. These materials are typically alloyed with small amounts of other metals to obtain desired physical properties, such as with beryllium, cadmium, silicon, magnesium, and the like. It is also possible to use silver, palladium, platinum; metals or alloys such as metals of the platinum group of elements. Solder constituted from lead, tin, indium, bismuth, cadmium, antimony and their alloys can be used.

Vis-a-vis attaching an end of the core (wire) to a terminal of an electronic component (discussed in greater detail hereinbelow), generally, a wire of any material (e.g., gold) that is amenable to bonding (using temperature, pressure and/or ultrasonic energy to effect the bonding) would be suitable for practicing the invention. It is within the scope of this invention that any material amenable to overcoating (e.g., plating), including non-metallic material, can be used for the core.

Suitable materials for the shell (114, 124, 134, 144) include (and, as is discussed hereinbelow, for the individual layers of a multi-layer shell), but are not limited to: nickel, and its alloys; copper, cobalt, iron, and their alloys; gold (especially hard gold) and silver, both of which exhibit

excellent current-carrying capabilities and good contact resistivity characteristics; elements of the platinum group; noble metals; semi-noble metals and their alloys, particularly elements of the platinum group and their alloys; tungsten and molybdenum. In cases where a solder-like finish is desired, tin, lead, bismuth, indium and their alloys can also be used.

The technique selected for applying these coating materials over the various core materials set forth hereinabove will, of course, vary from application-to-application. Electroplating and electroless plating are generally preferred techniques. Generally, however, it would be counter-intuitive to plate over a gold core. According to an aspect of the invention, when plating (especially electroless plating) a nickel shell over a gold core, it is desirable to first apply a thin copper initiation layer over the gold wire stem, in order to facilitate plating initiation.

An exemplary interconnection element, such as is illustrated in **Figures 1A-1E** may have a core diameter of approximately 0.001 inches and a shell thickness of 0.001 inches - the interconnection element thus having an overall diameter of approximately 0.003 inches (i.e., core diameter plus two times the shell thickness). Generally, this thickness of the shell will be on the order of 0.2 - 5.0 (one-fifth to five) times the thickness (e.g., diameter) of the core.

Some exemplary parameters for composite interconnection elements are:

(a) A gold wire core having a diameter of 1.5 mils is shaped to have an overall height of 40 mils and a generally C-shape curve (compare **Figure 1E**) of 9 mils radius, is plated with 0.75 mils of nickel (overall diameter = 1.5 + 2 x 0.75 = 3 mils), and optionally receives a final overcoat of 50 microinches of gold (e.g., to lower and enhance contact

resistance). The resulting composite interconnection element exhibits a spring constant (k) of approximately 3-5 grams/mil. (As used herein, the term "**spring constant**" refers to force per unit deflection.) In use, 3-5 mils of deflection will result in a contact force of 9-25 grams. This example is useful in the context of a spring element for an interposer.

(b) A gold wire core having a diameter of 1.0 mils is shaped to have an overall height of 35 mils, is plated with 1.25 mils of nickel (overall diameter = 1.0 + 2 x 1.25 = 3.5 mils), and optionally receives a final overcoat of 50 microinches of gold. The resulting composite interconnection element exhibits a spring constant (k) of approximately 3 grams/mil, and is useful in the context of a spring element for a probe.

(c) A gold wire core having a diameter of 1.5 mils is shaped to have an overall height of 20 mils and a generally S-shape curve with radii of approximately 5 mils, is plated with 0.75 mils of nickel or copper (overall diameter = 1.5 + 2 x 0.75 = 3 mils). The resulting composite interconnection element exhibits a spring constant (k) of approximately 2-3 grams/mil, and is useful in the context of a spring element for mounting on a semiconductor device.

According to the present invention, the core element need not have a round cross-section, but may rather be a flat tab ("ribbon") having a generally rectangular cross-section. extending from a sheet. It should be understood that, as used herein, the term "tab" is not to be confused with the term "TAB" (Tape Automated Bonding). Other non-circular cross-sections, such as C-shaped, I-shaped, L-shaped and T-shaped are within the scope of the invention.

MULTI-LAYER SHELLS

Figure 2A illustrates an embodiment 200 of an interconnection element 210 mounted to an electronic component

212 which is provided with a terminal 214. In this example, a soft (e.g., gold) wire core 216 is bonded (attached) at one end 216a to the terminal 214, is configured to extend from the terminal and have a spring shape (compare the shape shown in **Figure 1B**), and is severed to have a free end 216b. Bonding, shaping and severing a wire in this manner is accomplished using wirebonding equipment. The bond at the end 216a of the core covers only a relatively small portion of the exposed surface of the terminal 214.

A shell (overcoat) is disposed over the wire core 216 which, in this example, is shown as being multi-layered, having an inner layer 218 and an outer layer 219, both of which layers may suitably be applied by plating processes. One or more layers of the multi-layer shell is (are) formed of a hard material (such as nickel and its alloys) to impart a desired resiliency to the interconnection element 210. For example, the outer layer 219 may be of a hard material, and the inner layer may be of a material that acts as a buffer or barrier layer (or as an activation layer, or as an adhesion layer) in plating the hard material 219 onto the core material 216. Alternatively, the inner layer 218 may be the hard material, and the outer layer 219 may be a material (such as soft gold) that exhibits superior electrical characteristics, including electrical conductivity and solderability. When a solder or braze type contact is desired, the outer layer of the interconnection element may be lead-tin solder or gold-tin braze material, respectively.

ANCHORING TO A TERMINAL

Figure 2A illustrates, in a general manner, another key feature of the invention - namely, that resilient interconnection element can be securely anchored to a terminal on an electronic component. The attached end 210a of the

interconnection element will be subject to significant mechanical stress, as a result of a compressive force (arrow "*F*") applied to the free end 210b of the interconnection element.

As illustrated in **Figure 2A**, the overcoat (218, 219) covers not only the core 216, but also the entire remaining (i.e., other than the bond 216a) exposed surface of the terminal 214 adjacent the core 216 in a continuous (non-interrupted) manner. This securely and reliably anchors the interconnection element 210 to the terminal, the overcoat material providing a substantial (e.g., greater than 50%) contribution to anchoring the resulting interconnection element to the terminal. Generally, it is only required that the overcoat material cover at least a portion of the terminal adjacent the core. It is generally preferred, however, that the overcoat material cover the entire remaining surface of the terminal. Preferably, each layer of the shell is metallic.

As a general proposition, the relatively small area at which the core is attached (e.g., bonded) to the terminal is not well suited to accommodating stresses resulting from contact forces ("F") imposed on the resulting composite interconnection element. By virtue of the shell covering the entire exposed surface of the terminal (other than in the relatively small area comprising the attachment of the core end 216a to the terminal), the overall interconnection structure is firmly anchored to the terminal. The adhesion strength, and ability to react contact forces, of the overcoat will far exceed that of the core end (216a) itself.

As used herein, the term "electronic component" (e.g., 212) includes, but is not limited to: interconnect and interposer substrates; semiconductor wafers and dies, made of any suitable semiconducting material such as silicon (Si) or gallium-

arsenide (GaAs); production interconnect sockets; test sockets; sacrificial members, elements and substrates, as described in the parent case; semiconductor packages, including ceramic and plastic packages, and chip carriers; and connectors.

The interconnection element of the present invention is particularly well suited for use as:

- interconnection elements mounted directly to silicon dies, eliminating the need for having a semiconductor package;
- interconnection elements extending as probes from substrates (described in greater detail hereinbelow) for testing electronic components; and
- interconnection elements of interposers (discussed in greater detail hereinbelow).

The interconnection element of the present invention is unique in that it benefits from the mechanical characteristics (e.g., high yield strength) of a hard material without being limited by the attendant typically poor bonding characteristic of hard materials. As elaborated upon in the parent case, this is made possible largely by the fact that the shell (overcoat) functions as a "superstructure" over the "falsework" of the core, two terms which are borrowed from the milieu of civil engineering. This is very different from plated interconnection elements of the prior art wherein the plating is used as a protective (e.g., anti-corrosive) coating, and is generally incapable of imparting the desired mechanical characteristic to the interconnection structure. And this is certainly in marked contrast to any non-metallic, anticorrosive coatings, such as benzotriazole (BTA) applied to electrical interconnects.

Among the numerous advantages of the present invention are that a plurality of free-standing interconnect structures are readily formed on substrates, from different levels thereof such as a PCB having a decoupling capacitor) to a common height above

the substrate, so that their free ends are coplanar with one another. Additionally, both the electrical and mechanical (e.g., plastic and elastic) characteristics of an interconnection element formed according to the invention are readily tailored for particular applications. For example, it may be desirable in a given application that the interconnection elements exhibit both plastic and elastic deformation. (Plastic deformation may be desired to accommodate gross non-planarities in components being interconnected by the interconnection elements.) When elastic behavior is desired, it is necessary that the interconnection element generate a threshold minimum amount of contact force to effect a reliable contact. It is also advantageous that the tip of the interconnection element makes a wiping contact with a terminal of an electronic component, due to the occasional presence of contaminant films on the contacting surfaces.

As used herein, the term "resilient", as applied to contact structures, implies contact structures (interconnection elements) that exhibit primarily elastic behavior in response to an applied load (contact force), and the term "compliant" implies contact structures (interconnection elements) that exhibit both elastic and plastic behavior in response to an applied load (contact force). As used herein, a "compliant" contact structure is a "resilient" contact structure. The composite interconnection elements of the present invention are a special case of either compliant or resilient contact structures.

A number of features are elaborated upon in detail, in the parent case, including, but not limited to: fabricating the interconnection elements on sacrificial substrates; gang-transferring a plurality of interconnection elements to an electronic component; providing the interconnection elements with contact tips, preferably with a rough surface finish;

employing the interconnection elements on an electronic component to make temporary, then permanent connections to the electronic component; arranging the interconnection elements to have different spacing at their one ends than at their opposite ends; fabricating spring clips and alignment pins in the same process steps as fabricating the interconnection elements; employing the interconnection elements to accommodate differences in thermal expansion between connected components; eliminating the need for discrete semiconductor packages (such as for SIMMs); and optionally soldering resilient interconnection elements (resilient contact structures).

Controlled Impedance

Figure 2B shows a composite interconnection element 220 having multiple layers. An innermost portion (inner elongate conductive element) 222 of the interconnection element 220 is either an uncoated core or a core which has been overcoated, as described hereinabove. The tip 222b of the innermost portion 222 is masked with a suitable masking material (not shown). A dielectric layer 224 is applied over the innermost portion 222 such as by an electrophoretic process. An outer layer 226 of a conductive material is applied over the dielectric layer 224.

In use, electrically grounding the outer layer 226 will result in the interconnection element 220 having controlled impedance. An exemplary material for the dielectric layer 224 is a polymeric material, applied in any suitable manner and to any suitable thickness (e.g., 0.1 - 3.0 mils).

The outer layer 226 may be multi-layer. For example, in instances wherein the innermost portion 222 is an uncoated core, at least one layer of the outer layer 226 is a spring material, when it is desired that the overall interconnection element exhibit resilience.

ALTERING PITCH

Figure 2C illustrates an embodiment 250 wherein a plurality (six of many shown) of interconnection elements 251..256 are mounted on a surface of an electronic component 260, such as a probe card insert (a subassembly mounted in a conventional manner to a probe card). Terminals and conductive traces of the probe card insert are omitted from this view, for illustrative clarity. The attached ends 251a..256a of the interconnection elements 251..256 originate at a first pitch (spacing), such as 0.050 - 0.100 inches. The interconnection elements 251..256 are shaped and/or oriented so that their free ends (tips) are at a second, finer pitch, such as 0.005 - 0.010 inches. An interconnect assembly which makes interconnections from a one pitch to another pitch is typically referred to as a "space transformer".

As illustrated, the tips 251b..256b of the interconnection elements are arranged in two parallel rows, such as for making contact to (for testing and/or burning in) a semiconductor device having two parallel rows of bond pads (contact points). The interconnection elements can be arranged to have other tip patterns, for making contact to electronic components having other contact point patterns, such as arrays.

Generally, throughout the embodiments disclosed herein, although only one interconnection element may be shown, the invention is applicable to fabricating a plurality of interconnection components and arranging the plurality of interconnection elements in a prescribed spatial relationship with one another, such as in a peripheral pattern or in a rectangular array pattern.

TECHNIQUES EMPLOYING SACRIFICIAL SUBSTRATES

The mounting of interconnection elements directly to terminals of electronic components has been discussed hereinabove. Generally speaking, the interconnection elements of the present invention can be fabricated upon, or mounted to, any suitable surface of any suitable substrate, including sacrificial substrates.

Attention is directed to the PARENT CASE, which describes, for example with respect to Figures 11A-11F fabricating a plurality of interconnection structures (e.g., resilient contact structures) as separate and distinct structures for subsequent mounting to electronic components, and which describes with respect to Figures 12A-12C mounting a plurality of interconnection elements to a sacrificial substrate (carrier) then transferring the plurality of interconnection elements en masse to an electronic component.

Figures 2D-2F illustrate a technique for fabricating a plurality of interconnection elements having preformed tip structures, using a sacrificial substrate.

Figure 2D illustrates a first step of the technique 250, in which a patterned layer of masking material 252 is applied onto a surface of a sacrificial substrate 254. The sacrificial substrate 254 may be of thin (1-10 mil) copper or aluminum foil, by way of example, and the masking material 252 may be common photoresist. The masking layer 252 is patterned to have a plurality (three of many shown) of openings at locations 256a, 256b, 256c whereat it is desired to fabricate interconnection elements. The locations 256a, 256b and 256c are, in this sense, comparable to the terminals of an electronic component. The locations 256a, 256b and 256c are preferably treated at this stage to have a rough or featured surface texture. As shown,

this may be accomplished mechanically with an embossing tool 257 forming depressions in the foil 254 at the locations 256a, 256b and 256c. Alternatively, the surface of the foil at these locations can be chemically etched to have a surface texture. Any technique suitable for effecting this general purpose is within the scope of this invention, for example sand blasting, peening and the like.

Next, a plurality (one of many shown) of conductive tip structures 258 are formed at each location (e.g., 256b), as illustrated by **Figure 2E**. This may be accomplished using any suitable technique, such as electroplating, and may include tip structures having multiple layers of material. For example, the tip structure 258 may have a thin (e.g., 10 - 100 microinch) barrier layer of nickel applied onto the sacrificial substrate, followed by a thin (e.g., 10 microinch) layer of soft gold, followed by a thin (e.g., 20 microinch) layer of hard gold, followed by a relatively thick (e.g., 200 microinch) layer of nickel, followed by a final thin (e.g., 100 microinch) layer of soft gold. Generally, the first thin barrier layer of nickel is provided to protect the subsequent layer of gold from being "poisoned" by the material (e.g., aluminum, copper) of the substrate 254, the relatively thick layer of nickel is to provide strength to the tip structure, and the final thin layer of soft gold provides a surface which is readily bonded to. The invention is not limited to any particulars of how the tip structures are formed on the sacrificial substrate, as these particulars would inevitably vary from application-to-application.

As illustrated by **Figure 2E**, a plurality (one of many shown) of cores 260 for interconnection elements may be formed on the tip structures 258, such as by any of the techniques of bonding a soft wire core to a terminal of an electronic component described hereinabove. The cores 260 are then

overcoated with a preferably hard material 262 in the manner described hereinabove, and the masking material 252 is then removed, resulting in a plurality (three of many shown) of free-standing interconnection elements 264 mounted to a surface of the sacrificial substrate, as illustrated by **Figure 2F**.

In a manner analogous to the overcoat material covering at least the adjacent area of a terminal (214) described with respect to **Figure 2A**, the overcoat material 262 firmly anchors the cores 260 to their respective tip structures 258 and, if desired, imparts resilient characteristics to the resulting interconnection elements 264. As noted in the PARENT CASE, the plurality of interconnection elements mounted to the sacrificial substrate may be gang-transferred to terminals of an electronic component. Alternatively, two widely divergent paths may be taken.

It is within the scope of this invention that a silicon wafer can be used as the sacrificial substrate upon which tip structures are fabricated, and that tip structures so fabricated may be joined (e.g., soldered, brazed) to resilient contact structures which already have been mounted to an electronic component.

As illustrated by **Figure 2G**, the sacrificial substrate 254 may simply be removed, by any suitable process such as selective chemical etching. Since most selective chemical etching processes will etch one material at a much greater rate than an other material, and the other material may slightly be etched in the process, this phenomenon is advantageously employed to remove the thin barrier layer of nickel in the tip structure contemporaneously with removing the sacrificial substrate. However, if need be, the thin nickel barrier layer can be removed in a subsequent etch step. This results in a plurality (three of many shown) of individual, discrete, singulated

interconnection elements 264, as indicated by the dashed line 266, which may later be mounted (such as by soldering or brazing) to terminals on electronic components.

It bears mention that the overcoat material may also be slightly thinned in the process of removing the sacrificial substrate and/or the thin barrier layer. However, it is preferred that this not occur.

To prevent thinning of the overcoat, it is preferred that a thin layer of gold or, for example, approximately 10 microinches of soft gold applied over approximately 20 microinches of hard gold, be applied as a final layer over the overcoat material 262. Such an outer layer of gold is intended primarily for its superior conductivity, contact resistance, and solderability, and is generally highly impervious to most etching solutions contemplated to be used to remove the thin barrier layer and the sacrificial substrate.

Alternatively, as illustrated by **Figure 2H**, prior to removing the sacrificial substrate 254, the plurality (three of many shown) of interconnection elements 264 may be "fixed" in a desired spatial relationship with one another by any suitable support structure 266, such as by a thin plate having a plurality of holes therein, whereupon the sacrificial substrate is removed. The support structure 266 may be of a dielectric material, or of a conductive material overcoated with a dielectric material. Further processing steps (not illustrated) such as mounting the plurality of interconnection elements to an electronic component such as a silicon wafer or a printed circuit board may then proceed. Additionally, in some applications, it may be desireable to stabilize the tips (opposite the tip structures) of the interconnection elements 264 from moving, especially when contact forces are applied thereto. To this end, it may also be desirable to constrain

movement of the tips of the interconnection elements with a suitable sheet 268 having a plurality of holes, such as a mesh formed of a dielectric material.

A distinct advantage of the technique 250 described hereinabove is that tip structures (258) may be formed of virtually any desired material and having virtually any desired texture. As mentioned hereinabove, gold is an example of a noble metal that exhibits excellent electrical characteristics of electrical conductivity, low contact resistance, solderability, and resistance to corrosion. Since gold is also malleable, it is extremely well-suited to be a final overcoat applied over any of the interconnection elements described herein, particularly the resilient interconnection elements described herein. Other noble metals exhibit similar desirable characteristics. However, certain materials such as rhodium which exhibit such excellent electrical characteristics would generally be inappropriate for overcoating an entire interconnection element. Rhodium, for example, is notably brittle, and may not perform well as a final overcoat on a resilient interconnection element. In this regard, techniques exemplified by the technique 250 readily overcome this limitation. For example, the first layer of a multi-layer tip structure (see 258) can be rhodium (rather than gold, as described hereinabove), thereby exploiting its superior electrical characteristics for making contact to electronic components without having any impact whatsoever on the mechanical behavior of the resulting interconnection element.

Figure 2I illustrates an alternate embodiment 270 for fabricating interconnection elements. In this embodiment, a masking material 272 is applied to the surface of a sacrificial substrate 274, and is patterned to have a plurality (one of many shown) of openings 276, in a manner similar to the technique described hereinabove with respect to **Figure 2D**. The openings

276 define areas whereat interconnection elements will be fabricated as free-standing structures. (As used throughout the descriptions set forth herein, an interconnection element is "free-standing" when is has a one end bonded to a terminal of an electronic component or to an area of a sacrificial substrate, and the opposite end of the interconnection element is not bonded to the electronic component or sacrificial substrate.)

The area within the opening may be textured, in any suitable manner, such as to have one or more depressions, as indicated by the single depression 278 extending into the surface of the sacrificial substrate 274.

A core (wire stem) 280 is bonded to the surface of the sacrificial substrate within the opening 276, and may have any suitable shape. In this illustration, only a one end of one interconnection element is shown, for illustrative clarity. The other end (not shown) may be attached to an electronic component. It may now readily be observed that the technique 270 differs from the aforementioned technique 250 in that the core 280 is bonded directly to the sacrificial substrate 274, rather than to a tip structure 258. By way of example, a gold wire core (280) is readily bonded, using conventional wirebonding techniques, to the surface of an aluminum substrate (274).

In a next step of the process (270), a layer 282 of gold is applied (e.g., by plating) over the core 280 and onto the exposed area of the substrate 274 within the opening 276, including within the depression 278. The primary purpose of this layer 282 is to form a contact surface at the end of the resulting interconnection element (i.e., once the sacrificial substrate is removed).

Next, a layer 284 of a relatively hard material, such as

nickel, is applied over the layer 282. As mentioned hereinabove, one primary purpose of this layer 284 is to impart desired mechanical characteristics (e.g., resiliency) to the resulting composite interconnection element. In this embodiment, another primary purpose of the layer 284 is to enhance the durability of the contact surface being fabricated at the lower (as viewed) end of the resulting interconnection element. A final layer of gold (not shown) may be applied over the layer 284, to enhance the electrical characteristics of the resulting interconnection element.

In a final step, the masking material 272 and sacrificial substrate 274 are removed, resulting in either a plurality of singulated interconnection elements (compare **Figure 2G**) or in a plurality of interconnection elements having a predetermined spatial relationship with one another (compare **Figure 2H**).

This embodiment 270 is exemplary of a technique for fabricating textured contact tips on the ends of interconnection elements. In this case, an excellent example of a "gold over nickel" contact tip has been described. It is, however, within the scope of the invention that other analogous contact tips could be fabricated at the ends of interconnection elements, according to the techniques described herein. Another feature of this embodiment 270 is that the contact tips are constructed entirely atop the sacrificial substrate (274), rather than within the surface of the sacrificial substrate (254) as contemplated by the previous embodiment 250.

INTERPOSERS

The composite interconnection (spring) elements of the present invention are applicable to a broad range of applications, for example, for use in interposers. The subject of using composite interconnection elements in interposers has been discussed in the PARENT CASE, and is only briefly elaborated upon herein.

Generally, as used herein, an "interposer" is a substrate having electrical contact structures extending from two opposite surfaces thereof, disposed between two electronic components to interconnect the two electronic components. Often, it is desirable that the interposer permit at least one of the two interconnected electronic components to be removed (e.g., for replacement, upgrading, and the like).

Figure 3 illustrates an embodiment 300 of an interposer, using the interconnection elements of the invention. Generally, an insulating substrate 302, such as a PCB-type substrate, is provided with a plurality (two of many shown) of electrically conductive through holes (e.g., plated vias) 306, 308, or the like, each having conductive portions exposed on the top (upper) 302a and bottom (lower) 302b surfaces of the insulating substrate 302.

A pair of soft cores 311 and 312 are attached to the exposed portion of the through hole 306 on the top surface 302a of the substrate 302. A pair of soft cores 313 and 314 are attached to the exposed portion of the through hole 306 on the bottom surface of the substrate 302. Similarly, a pair of soft cores 315 and 316 are attached to the exposed portion of the through hole 308 on the top surface of the substrate 302, and a pair of soft cores 317 and 318 are attached to the exposed portion of the through hole 308 on the bottom surface of the

substrate 302. The cores 311..318 are then overcoated with a hard material 320 to form interconnect structures 322 and 324 on the top surface 302a of the substrate 302 and to form interconnect structures 326 and 328 on the bottom surface 302b of the substrate 302. In this manner, the individual cores 311..318 are securely anchored to the respective exposed portions of the through holes, the interconnecting structure 322 is electrically connected to the interconnecting structure 326, and the interconnecting structure 324 is electrically connected to the interconnecting structure 328. It will be understood that by providing each interconnecting structure (e.g., 322) as a pair of interconnecting elements (e.g., 311, 312), that more reliable connections to external components (not shown) are effected (i.e., than with single interconnecting elements).

As is shown, the top group of interconnection elements 311, 312, 315 and 316 are all formed with the same shape, and the bottom group of interconnection elements all have the same shape. It should be understood that the bottom group of interconnection elements can be provided with a shape which is different than the top group of interconnection elements, which would provide the opportunity to create interconnecting structures extending from the top surface of the insulating substrate having dissimilar mechanical characteristics from the interconnecting structures extending from the bottom surface of the substrate.

OBTAINING INCREASED CONTACT FORCE

A principal purpose of the composite interconnection element of the present invention is to permit pressure connections to be made between electronic components.

As mentioned above, one of the principal concerns in effecting a pressure connection is the contact force provided by the spring contact element. As a general proposition, it is desired to maximize the contact force, or have a higher spring constant for the resilient connection made by the spring element(s).

In the example of an interposer 300 set forth hereinabove, each resilient connection is made by a pair of composite interconnection elements. The contact force for each connection will be the sum of contact forces contributed by each interconnection element of the pair.

According to an aspect of the invention, rather than using two or more composite interconnection elements fabricated from core elements having a round cross-section (i.e., wire stems) to effect a single pressure connection, a single pressure connection is effected by a single composite interconnection element having a cross-section which is non-circular and which is selected to maximize the contact force which can be provided by the composite interconnection element.

Figures 4 and 4A illustrate an example of a freestanding composite interconnection element 400 mounted to a terminal 402 of an electronic component 404. For purposes of this example, the composite interconnection element 400 has a spring shape similar to the composite interconnection element 150 of **Figure 3**, but is not limited to any particular spring shape. The composite interconnection element 400 has an inner core 406

which is a soft (e.g., gold) wire having a round (circular) cross-section, and is overcoated with a hard (e.g., nickel) material 408, as described hereinabove.

Such a composite interconnection element 400 will exhibit a given (calculable) amount of contact force "F" when the component 404 is urged against another (not shown) component - namely, when the composite interconnection element is caused to deflect a given distance.

The core element (wire stem) 406 is bonded to the terminal 402 by a conventional wire bonder, resulting in a "ball" bond 410, as illustrated in **Figure 4**. The single terminal 402a (compare 402) to which the spring element 400 is mounted is shown in dashed lines.

As described hereinabove with respect to **Figure 3**, a pressure contact can be made with a pair of composite interconnection elements (e.g., 400) extending from a single terminal on an electronic component and contacting a corresponding single terminal on an electronic component. In such a case, for a given amount of deflection, the contact force would be 2F, each of the interconnection elements contributing a contact force "F", as described hereinabove. **Figure 4B** illustrates such a situation, in cross-section. The single terminal 402b (compare 402) to which the pair of spring elements 400 is mounted is shown in dashed lines. Again, this is not limited to any particular electronic component or to any particular spring shape.

RIBBON-LIKE CORE ELEMENTS

The use of a wire having other than a circular cross-section has been disclosed in a number of the commonly-owned, copending cases.

For example, commonly-owned, copending U.S. Patent Application No. 08/452,255 states, at page 63, lines 4-6:

> "The wire need not have a circular cross-section ... [it] may have a rectangular cross-section, or may have a cross-section of yet another shape."

Figure 5 is a perspective view of an embodiment 500 ribbon-like core element 502 extending from a terminal 504 of an electronic component 506. The core element 502 is formed of any suitable soft material, in a manner comparable to the wire stems described hereinabove.

Rather than being a wire, for example a wire having a diameter of 1.0 mils, the ribbon-like core element 502 is generally rectangular in cross-section, having a first transverse dimension "**d1**" greater than a second transverse dimension "**d2**" in a direction orthogonal to the first dimension "**d1**". The dimension "**d1**" is preferably at least twice (two times) as large (including three, four, and more) as the dimension "**d2**". For example:

- the dimension "**d1**" (or width) may be <u>0.001 - 0.010 inches</u>, for example 5.0 mils; and
- the dimension "**d2**" (or thickness) may be <u>0.0003 - 0.0015 inches</u>, for example 1.0 mils.

An overcoat material (not shown, illustrated in **Figure 5B**) is applied over the core element in the manner set forth hereinabove, and is suitably a multi-layer overcoat including at least one layer of a high yield strength material such as nickel (and is alloys).

Generally, since the ribbon-like core element (e.g., 502) has such a large surface (particularly cross-sectional and its distribution relative to a bending moment) area, it is not necessary to provide as much thickness of the overcoat material to achieve a similar spring constant as with one or more comparably-sized interconnection elements having wire stems (core elements of circular cross-section). In practice, a ribbon-like core element (502) can be overcoated to provide a composite interconnection element having a higher spring constant than a similarly-sized composite interconnection element of equal or greater thickness having a wire stem, and to be thinner overall than a comparable composite interconnection element having a wire stem.

By having a core element of non-circular cross-section, a number of advantages over composite interconnection elements having round cross-section core elements will accrue, including:

- the same or a higher spring constant (k) value, hence greater contact force for the composite interconnection element, can be obtained, with less plating (overcoat) than would be required to overcoat two or more wire stems having a circular cross-sections;
- as the ribbon-like spring element is compressed, stress distribution will be improved (a rectangular cross-sectional beam will, for same reaction force, exhibit a lower stress in the section than a comparable circular cross-sectional beam. In other words, a rectangle is a more efficient cross-section.);
- less stress in the spring element will result in greater elastic deformation (springiness); and
- the major dimension (d1) of the core element can be oriented so that the resulting spring element will exhibit greater stability against lateral (in and out of the page, as viewed in the figure) motion during compression.

The ribbon-like core element (502) may have a rectangular cross-section with sharp edges (corners). However, these corners can also be rounded or chamfered. Generally, such core elements are made by rolling (flattening) a wire which initially has a round cross-section.

It is within the scope of this invention that a ribbon-like core element can be other than rectangular in cross-section, including elliptical, oval, I-beam shaped and C-beam shaped. Composite interconnection elements fabricated from such ribbon-like core elements will exhibit some or all of the advantages set forth above with respect to rectangular cross-section ribbon-like core elements.

BONDING THE RIBBON-LIKE CORE ELEMENT TO A TERMINAL

As mentioned hereinabove, any suitable means may be employed to "tack" the core element to the terminal so that it can be overcoated, the overcoat providing a major portion of the anchoring of the resulting composite interconnection element to the terminal.

It is generally preferred, however, that the ribbon-like core element be bonded to the terminal in a manner similar to which a wire stem is bonded to the terminal - namely, using generally conventional wirebonding equipment to effect a ball (versus wedge) bond of the core element to the terminal. (Evidently, the bore in the capillary of the wirebonder will need to be adapted (shaped) to receive and feed such ribbon-like elements.)

Figure 5A illustrates a technique 550 whereby a ribbon-like core element 552 (compare 502) is ball bonded to a terminal 554 (compare 504) on an electronic component 556 (compare 506), shaped to have a spring shape, and severed to be free-standing. An overcoat is applied to the free-standing, ribbon-like core element, in the manner described hereinabove.

A ball bond 558 is formed at the proximal end 552a of the core element 552 which is affixed to the terminal 554. Generally, in order to form such a ball bond with a ribbon-like core element, multiple firings (versus one firing) may be required.

In a similar manner, it is preferred that a ball 560 be formed at the distal end (tip) 552b of the core element 552. Again, multiple firings of an EFO electrode may be required to effectively form the desired ball at the tip of the core element.

It is within the scope of this invention that ribbon-like conductive elements other than core elements for composite interconnection elements be ball-bonded in this manner to terminals of electronic components.

Figure 5B shows, in cross-section, the core element 552 of **Figure 5A**, after applying an overcoat, in the manner described hereinabove. As mentioned above, the overcoat 562 for such a ribbon-like core element can be significantly thinner (e.g., having a nominal thickness of less than 1.0 mils) than an overcoat for one or more comparable wire stems having circular cross-sections to achieve the same (or greater) contact force, while improving stress distribution during compression of the resulting composite interconnection element.

Figure 5C illustrates a composite interconnection element 550 (generally, a perspective view of the interconnection element 550 of **Figure 5A**) formed by ball-bonding a flat (rectangular cross-section) core element 552 to a terminal (which may simply be a selected area) 554 on a substrate 556 (which may be an electronic component). The core element 552 is shaped, either before or after bonding, to have a spring shape. An exemplary one of many such spring shapes is illustrated in the figure. The ribbon-like core element 552 is then overcoated with one or more layers of material 558 to impart desired characteristics to the resulting interconnection element, as described hereinabove. Again, multiple firings of an electrode (electrical discharge, spark) may be required to form the ball at the tip (unmounted end) of the element 550.

Figure 5D illustrates a cross-section of the interconnection element 550, and **Figure 5E** illustrates the cross-sections of a plurality (e.g., five) of interconnection elements 560 fabricated from core elements having round cross-

sections and having comparable dimensions. For example:

- the interconnection element 550 of **Figure 5D** includes a single flat (ribbon-like) core element 552 having a thickness (vertical, in the figure) of 1 mil, and a width (horizontal in the figure) of 5 mils, and is overcoated by a material having a thickness of 1 mil; and
- each of the five interconnection elements 560 illustrated in **Figure 5E** includes a core element 562 having a diameter of 1 mil and an overcoat thickness of 1 mil.

Each of the interconnection elements 560 provides a contact force of **1F**, as illustrated by the arrows in the figure. In aggregate, the five interconnection elements 560 would provide a contact force of **5F**. (It will be understood that the contact force is directed generally into the page.)

The single ribbon-like interconnection element 550, formed of the same materials and of comparable dimensions as the five interconnection elements 560 will exhibit a contact force of approximately **10-20F**, such as **15F**, which is evidently much greater than the aggregate contact force (5F) provided by the five interconnection elements 560. (Again, it will be understood that the contact force is directed generally into the page.)

Hence it can be appreciated that an interconnection element (e.g., 550) having a non-circular cross-section can provide increased contact force, decreased stress, and increased elastic range, as contrasted with a plurality of circular cross-section interconnection elements. This is generally true whether the interconnection element (e.g., 550) is "composite" or "monolithic". Additionally, whereas five individual wirebonding operations would be required to form the structure 560 illustrated in **Figure 5D**, only one (i.e., a single) wire bonding operation is required to form the interconnection element of

Figures 5C and 5D.

CAPILLARY

The interconnection element of the present invention advantageously employs the process of ball bonding an end of a flat (non-circular cross-section) wire to a substrate (including to a terminal of an electronic component). This can be done with a conventional wirebonder, equipped with an appropriate capillary.

Figures 6A and 6B illustrate, in cross-section, an exemplary capillary 600 for a wirebonder (such as a K&S model 1419 wirebonder), according to the present invention. As is known, a conventional capillary has a body portion and a bore extending centrally therethrough, and wire (e.g., bond wire) is fed through the capillary and exits the tip of the capillary.

The capillary 600 has a body portion 602 and a bore 604 extending completely through the body portion from top (as viewed) to bottom (as viewed). The bottom end of the capillary is the tip 606. As is best viewed in **Figure 6B**, the bore 604 has a non-circular cross-section. Rather, the cross-section is in the form of a rounded rectangle, having a minor dimension **T** somewhat (e.g., 0.5 mil) larger than the core element dimension **d2**, and a major dimension **W** somewhat (e.g., 0.5 mil) larger than the core element dimension **d1**. For a ribbon having the following dimensions, the capillary dimensions are suitably (all dimensions are in inches):

d2	d1	W	T
0.0005	0.0015	0.0020	0.0010
0.0005	0.0025	0.0030	0.0010

0.0010 0.0050 0.0057 0.0015

The end (as viewed in **Figure 6B**) of the bore is suitably (e.g., 1 mil) radiussed to accommodate passage of the core element therethrough and the bore 604 has a draft angle of approximately 10° (larger at the top than at the tip).
The external surface of the capillary body 602 is radiussed (as shown) at the tip 606, and the bore 604 is also suitably radiussed (as shown) where it exits the tip 606.

Hence, there is disclosed a method of ball-bonding a conductive ribbon (in the case of a precursor to a composite interconnection element, the ribbon is a core element) to an area (which may be a terminal) on a surface of a substrate (which may be an electronic component), which includes
passing a ribbon (or core element) through a similarly shaped (in cross-section) capillary of a wirebonder, the ribbon exiting from a tip of the capillary and preferably having a ball (region of increased cross-dimension) previously formed at the end of the ribbon, urging the tip of the capillary against the area on the surface of the substrate; and applying one or more energies selected from the group consisting of any combination of ultrasonic energy, thermal energy and compressive forces to effect a ball bond between the end of the ribbon and the substrate. The capillary disclosed herein may be used with any of:

(a) ultrasonic wirebonders;
(b) thermosonic wirebonders; and
(c) thermocompression wirebonders.

In use, after the ribbon is ball-bonded to the substrate, the capillary is withdrawn (z-axis) so that the ribbon extends from the surface of the substrate. During this operation, x-

y movement may be imparted (e.g., by a stage upon which the substrate is resting) to impart a spring shape to the ribbon. Alternatively, as described hereinbelow, a separate mechanical instrumentality (a shaping tool) can be used to impart a spring shape to the ribbon.

After withdrawing the capillary, the ribbon is severed form a free-standing structure (which may be the core element of a composite interconnection element) bonded to the substrate, and a remaining portion of the ribbon remains in the capillary and extending from the tip thereof in preparation for making a subsequent ball-bond to the substrate. Preferably, before ball-bonding (i.e., after a previous severing operation), a ball is formed at the end of the remaining portion of the ribbon, for forming the subsequent bond to the substrate.

It is within the scope of this invention that the ball is formed at the end of the ribbon (at a portion of the ribbon which is extending past the tip of the capillary) by employing a spark (**electrical discharge**) initiated by an electronic flame off (EFO) electrode. Preferably, the electrode is oriented so that the spark strikes the ribbon on its narrow side (d2, see **Figure 5**), rather than striking the ribbon "broadside". It is also within the scope of this invention that multiple firings of the EFO electrode may be required to sever the ribbon and/or to form a ball at the end of the ribbon.

In a manner analogous to conventional wirebonding; the ribbon may be formed of a material selected from the group consisting of gold, copper, aluminum and their alloys.

SHAPING AND SEVERING RIBBON-LIKE CORE ELEMENTS

As discussed in the PARENT CASE, elongate core elements are readily caused to have a spring shape by causing relative motion between the capillary and the component (substrate) to which the elongate core element is bonded, prior to severing the core element to be a free-standing wire stem.

According to an aspect of this invention, ribbon-like core elements (e.g., 502, 552) are suitably shaped using an external mechanical instrumentality such as disclosed in commonly-owned, copending U.S. Patent Application No. 60/013,247, incorporated by reference herein. A description of an exemplary external mechanical shaping instrumentality is described hereinbelow.

Figures 7A-7C illustrate an embodiment 700 of a technique for shaping a portion of an elongate element 702 extending between an area 710 of a substrate 708, such as a terminal of an electronic component, and a capillary 704 (compare 600) of a wirebonder (not shown). The elongate element 702 is suitably supplied by a supply spool 706.

In this exemplary embodiment, the shaping tool 712 is a rod (cylindrical element) that is moved in the x-y plane by an actuator ("ACT") 720 such as a solenoid. The dashed line 722 between the rod and the actuator signifies any suitable linkage elements such as levers. Preferably, the actuator 720 is of a type, the motion and position of which can be controlled (e.g., by software), such as a combination motor/encoder or servo system, over its entire range of motion. In this manner, the force applied by the shaping tool to the elongate element and the travel of the shaping tool can be carefully controlled and profiled. It is within the scope of the invention, however, that a simple solenoid can be used as the actuator, the "throw" (distance that the solenoid moves) of the solenoid being limited

by a suitable mechanical stop associated with the linkage (or, with the shaping tool itself).

The shaping tool 712 is formed of a material which is harder than the material of the elongate element 702, such as tungsten, quartz, or the like. It is within the scope of this invention that the shaping tool can be heated, such as with an excimer laser, to aid in shaping the elongate element. It is within the scope of this invention that an electrical potential (including grounding) can be applied to the shaping tool for controlling a severing spark applied to the elongate element.

Figure 7B shows the shaping tool 712 being urged against the elongate element 702, causing the elongate element to have a spring shape. **Figure 7C** shows the shaping tool having been withdrawn from the elongate element 702, and the elongate element having been severed adjacent the capillary 704.

In **Figures 7B and 7C**, the elongate element 702 is illustrated as having been caused to have a shape similar to the shape shown in **Figure 1E** (a C-shape). The diameter of the shaping tool 712 is preferably slightly less that the final height of the shaped elongate element. For example, a shaped elongate element having a height of 30-35 mils can be appropriately shaped by a cylindrical shaping tool having a diameter of 20-25 mils. This is but one of many possible spring shapes that can be imparted to the elongate element.

Preferably, in the embodiment 700, the elongate element 702 is severed by a spark (**electrical discharge**) from an electronic flame off (EFO) electrode 732 which is fixed to the capillary 704.

It is within the scope of this invention that the elongate element is severed with a spark 714, while the shaping tool 512

is in mechanical and electrical contact (engagement) with the elongate element 702, as illustrated in **Figure 7A**. The shaping tool 712 could be grounded, or at a given potential to control the spark and/or to prevent the spark from damaging a delicate electronic component (708).

In the previously-described embodiment 700 of using a shaping tool 712 to impart a spring shape to the elongate element (e.g., bond wire), the bond wire is first bonded to the substrate and the capillary 704 is withdrawn in the z-axis to feed out the portion of the bond wire which is desired to be shaped.

It is within the scope of this invention that a shaping tool can have a plurality of degrees of freedom, and may be moved in a manner that the elongate element twists around the shaping tool, to impart complex shapes to the shaped portion of the elongate element.

The use of an external shaping tool (versus imparting relative motion between the capillary and the component) to impart the desired spring shape to the elongate element is generally preferred for reliable shaping of ribbon-like core elements.

As mentioned hereinabove, the present invention differs dramatically from the prior art in that an overcoat is used to impart desired mechanical characteristics (e.g., elasticity) to an otherwise non-elastic, readily-formed, inchoate interconnection element (contact structure). In the prior art, coatings (including gold platings) are principally used to enhance electrical characteristics of interconnection elements, and to prevent corrosion thereof.

Interconnection elements can either be fabricated "in-situ" on electronic components, or "pre-fabricated" for later mounting to electronic components.

Although the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character - it being understood that only preferred embodiments have been shown and described, and that all changes and modifications that come within the spirit of the invention are desired to be protected. Undoubtedly, many other "variations" on the "themes" set forth hereinabove will occur to one having ordinary skill in the art to which the present invention most nearly pertains, and such variations are intended to be within the scope of the invention, as disclosed herein. Several of these variations are set forth in the PARENT CASE.

For example, a composite interconnection element can be fabricated with a ribbon-like core element and can be used as a spring contact for a probe, a spring contact for a variety of interposers, a spring contact on silicon, a spring contact having controlled impedance, etc.

For example, rather than ball bonding the ribbon-like core element, it may be wedge bonded.

For example, a one end of the core element can be bonded to a sacrificial substrate or layer (see, e.g., the aforementioned U.S. Patent Application No. 08/152,812), the other end bonded to a terminal on an electronic component.

CLAIMS

What is claimed is:

1. Method of ball-bonding an elongate conductive element to an area on a surface of a substrate, comprising:

passing the elongate conductive element through a capillary, said elongate conductive element exiting at a tip of the capillary;

urging the tip of the capillary against an area on a surface of a substrate; and

applying one or more energies selected from the group consisting of ultrasonic energy, thermal energy and compressive forces to the capillary, to effect a ball bond between an end of the elongate conductive element and the substrate;

characterized in that the elongate conductive element is a ribbon.

2. Method, according to claim 1, characterized by:

after ball-bonding the ribbon to the area on the surface of the substrate, withdrawing the capillary so that the ribbon extends from the surface of the substrate.

3. Method, according to claim 2, characterized by:

after withdrawing the capillary, severing the ribbon to form a free-standing structure bonded to the substrate, a remaining portion of the ribbon remaining in the capillary and extending from the tip thereof.

4. Method, according to claim 3, characterized by:

forming a ball at an end of the remaining portion of the ribbon, for forming a subsequent bond to the substrate.

5. Method, according to claim 1, characterized by:

prior to urging the tip against the substrate, forming a ball at an end of the ribbon extending from the tip.

6. Method, according to claim 5, characterized in that:
the step of forming the ball at the end of the ribbon is effected by electronic flame off process.

7. Method, according to claim 1, characterized in that:
the ribbon is formed of a material selected from the group consisting of gold, copper, aluminum and their alloys.

8. Method, according to claim 1, characterized in that:
the substrate is an electronic component; and
the area is a terminal on the electronic component.

9. Method, according to claim 1, further comprising:
after bonding the ribbon to the area on the substrate, overcoating the ribbon.

10. Method, according to claim 1, characterized in that:
the ribbon is a core element of a composite interconnection element.

11. Method of making a spring contact, characterized by:
shaping a ribbon-like core element of a readily-shaped material to have a springable shape; and
overcoating the core element with a material of sufficient thickness and of sufficient yield strength to impart a desired amount of resiliency to the resulting spring contact and to dominate said resiliency.

12. Method, according to claim 11, characterized in that:
the core element is a material selected from the group consisting of gold, copper, aluminum and their alloys.

13. Method, according to claim 11, characterized in that:
the core element is overcoated with a material

selected from the group consisting of nickel and its alloys.

14. Method, according to claim 11, characterized in that:

the core element has a thickness along a one axis of 0.0003 - 0.0015 inches.

15. Method, according to claim 14, characterized in that:

the core element has a thickness along another axis orthogonal to the one axis of 0.001 - 0.010 inches.

16. Method, according to claim 11, characterized in that:

the core element has a first transverse dimension d1 and a second transverse dimension d2; and

the first transverse dimensions is at least two times greater than the second transverse dimension.

17. Method of mounting an interconnection element to a terminal of an electronic component, characterized by:

attaching a ribbon-like core element to a terminal of an electronic component; and

overcoating the core element and at least an adjacent portion of the terminal with a material of sufficient thickness and of sufficient yield strength to securely mount the resulting composite interconnection element to the terminal, said overcoating material making a substantial contribution to anchoring the resulting interconnection element to the terminal.

18. Method, according to claim 17, characterized in that:

the core element is a material selected from the group consisting of gold, copper, aluminum and their alloys.

19. Method, according to claim 17, characterized in that:

the core element is overcoated with a material selected from the group consisting of nickel and its alloys.

20. Method, according to claim 17, characterized in that: the core element has a thickness of 0.0003 - 0.0015 inches in a first axis, and a thickness of 0.0010 - 0.010 inches in a second orthogonal axis.

21. Method, according to claim 17, characterized in that: the material overcoating the core element has a nominal thickness of less than 0.0010 inches.

22. Method of fabricating interconnection elements, characterized by:

mounting a plurality of ribbon-like core elements to a surface of a sacrificial substrate;

overcoating the core elements with at least one layer of at least one material; and

removing the sacrificial substrate.

23. Method, according to claim 22, further comprising:

prior to removing the sacrificial substrate, mounting the overcoated core elements to terminals of an electronic component.

24. Method of making an interconnection element for use in microelectronic applications, characterized by:

providing a ribbon-like core element of a relatively soft material; and

overcoating the core element with a shell of a relatively hard material.

25. Method, according to claim 24, characterized in that: the core is overcoated by a process selected from the group consisting of various processes involving deposition of materials out of aqueous solutions; electrolytic plating; electroless plating; chemical vapor deposition (CVD); physical vapor deposition (PVD); and processes causing the disintegration

of liquids, solids or gases.

26. Method, according to claim 24, characterized in that: the core element is a material selected from the group consisting of gold, copper, aluminum, and their alloys.

27. Method, according to claim 24, characterized in that: the shell is a material selected from the group consisting of nickel and its alloys.

28. Method, according to claim 24, characterized in that: the core element has a first yield strength; the shell has a second yield strength; and the second yield strength is at least twice the first yield strength.

29. Method of mounting an interconnection element to a terminal of an electronic component, characterized by: attaching a ribbon-like elongate element of a first material to a terminal of an electronic component; and overcoating the elongate element with a second material which has a higher yield strength than the first material.

30. Method, according to claim 29, characterized by: while overcoating the elongate element, overcoating at least a portion of an exposed surface of the terminal with the second material.

31. Method, according to claim 29, characterized in that: the core element is overcoated by a process selected from the group consisting of various processes involving deposition of materials out of aqueous solutions; electrolytic plating; electroless plating; chemical vapor deposition (CVD); physical vapor deposition (PVD); and processes causing the

disintegration of liquids, solids or gases.

32. Method, according to claim 29, characterized in that:
the first material is selected from the group consisting of gold, copper, aluminum, and their alloys.

33. Method, according to claim 29, characterized in that:
the second material is selected from the group consisting of nickel and its alloys.

34. Method, according to claim 29, characterized in that:
the elongate element is overcoated with a multi-layer coating, at least one layer of which is formed of the second material.

35. Method of making an interposer, characterized by:
overcoating a plurality of ribbon-like elongate elements formed of a first material with a second material which has a higher yield strength than the first material; and
supporting the plurality of overcoated ribbon-like elongate elements in a prescribed spatial relationship with one another.

36. Method of making an interconnection element having controlled impedance, for use in microelectronic applications, characterized by:
shaping a ribbon-like core element to have a springable shape;
applying a dielectric material over the core element;
overcoating the layer of dielectric material with a conductive material.

37. Method, according to claim 36, characterized by:
prior to applying the dielectric material, overcoating the core element with a material of sufficient thickness and of

sufficient yield strength to impart a desired amount of resiliency to the resulting interconnection element.

38. An interconnection element for microelectronics, characterized by:

a ribbon-like core formed of a soft material; and

a hard material, disposed over the core,

characterized in that:

said hard material is selected for its ability to impart resilience to the resulting interconnection element.

39. An interconnection element, according to claim 38, characterized in that:

the core has a yield strength of less than 40,000 psi; and

the hard material has a yield strength of greater than 80,000 psi.

40. An interconnection element, according to claim 38, characterized in that:

a one end of the core is attached to a terminal on an electronic component and the core extends from the terminal.

41. Capillary for a wirebonder, comprising:

a body having a bore extending therethrough, the bore extending from a one end of the capillary to an opposite tip of the capillary, said bore having an end at the tip of the capillary;

characterized in that:

the end of the bore has a non-circular shape.

42. Capillary, according to claim 41, characterized in that:

the bore has a cross-section is in the form of a rounded rectangle.

43. Capillary, according to claim 42, characterized in that:

the end of the bore has a minor dimension **T** and a major dimension **W**; and

the major dimension is at least twice as great as the minor dimension.

44. Capillary, according to claim 43, characterized in that:

the minor dimension is in the range of from 0.0010 - 0.0015 inches, and the major dimension is in the range of from 0.0020 - 0.0057 inches.

45. Capillary, according to claim 41, characterized in that:

the bore has a draft angle of approximately 10° between the one end and the tip of the capillary.

Figure 1A

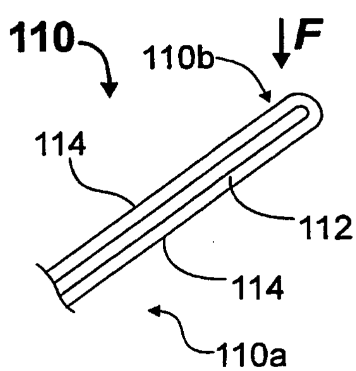


Figure 1B

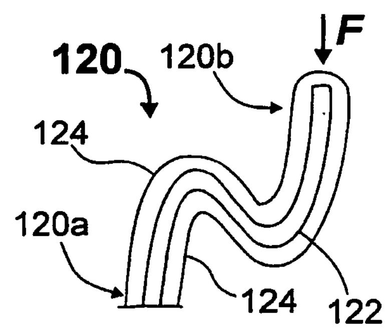


Figure 1C

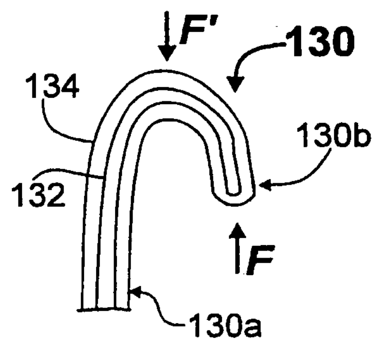


Figure 1D

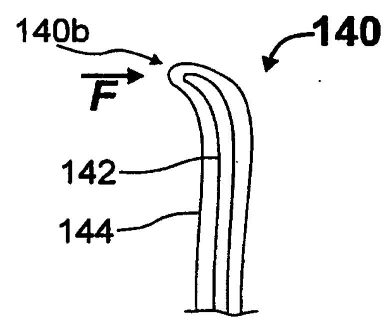


Figure 1E

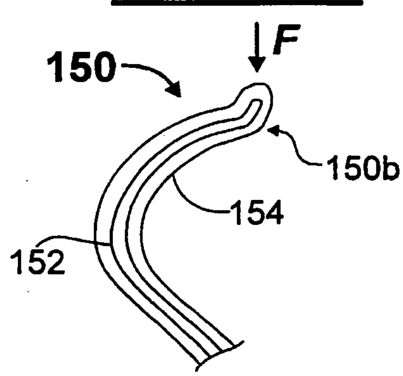


Figure 2A

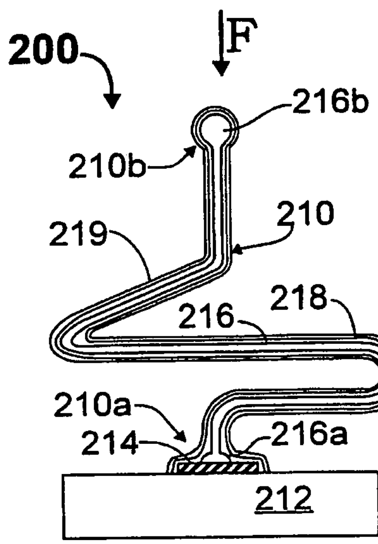


Figure 2B

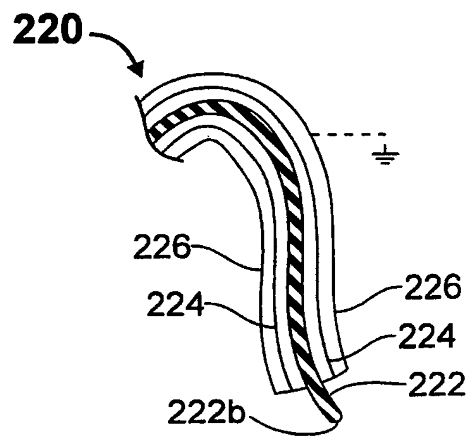


Figure 2C

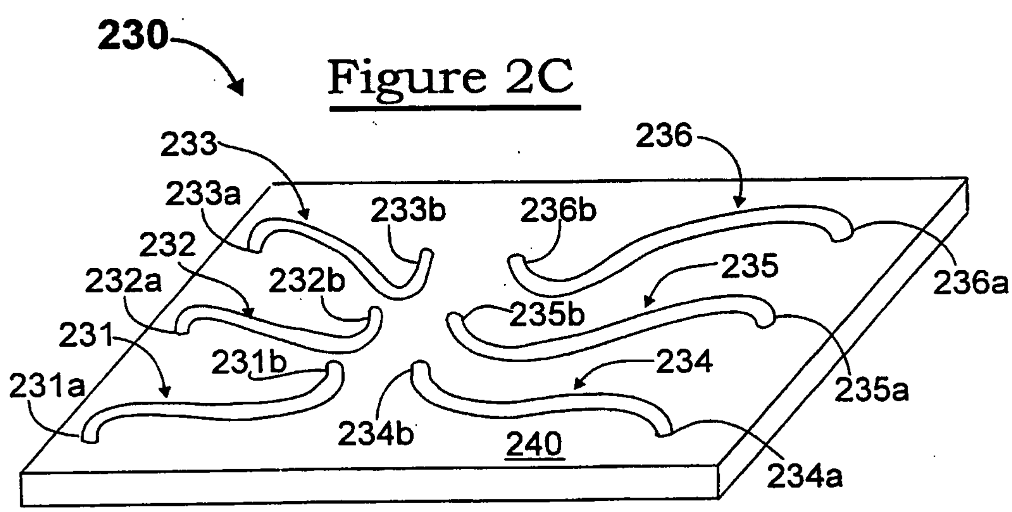


Figure 2D

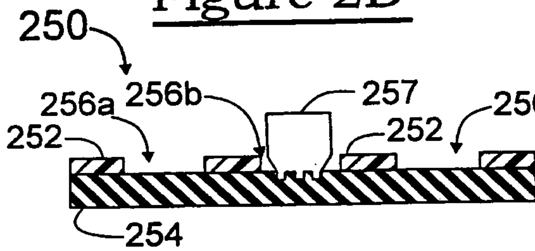


Figure 2E

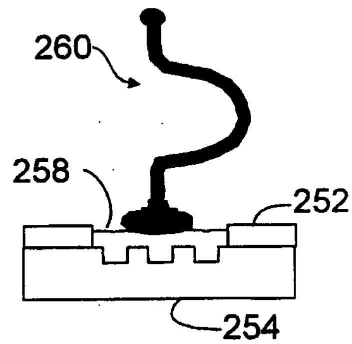


Figure 2F

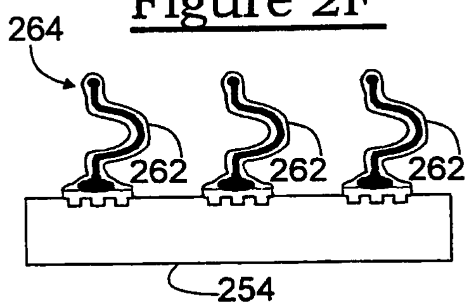


Figure 2G

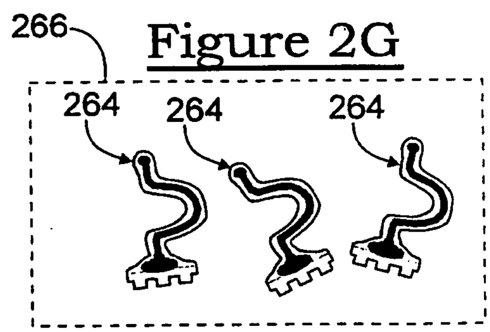


Figure 2H

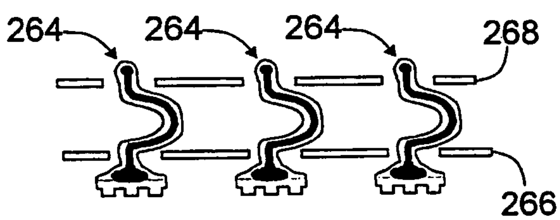


Figure 2I

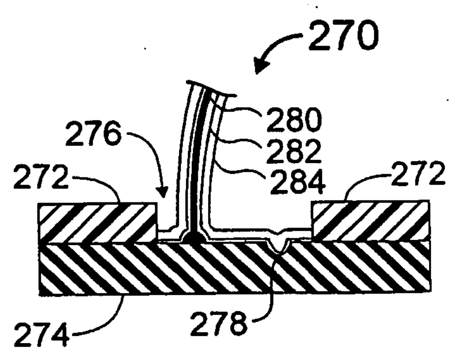


Figure 3

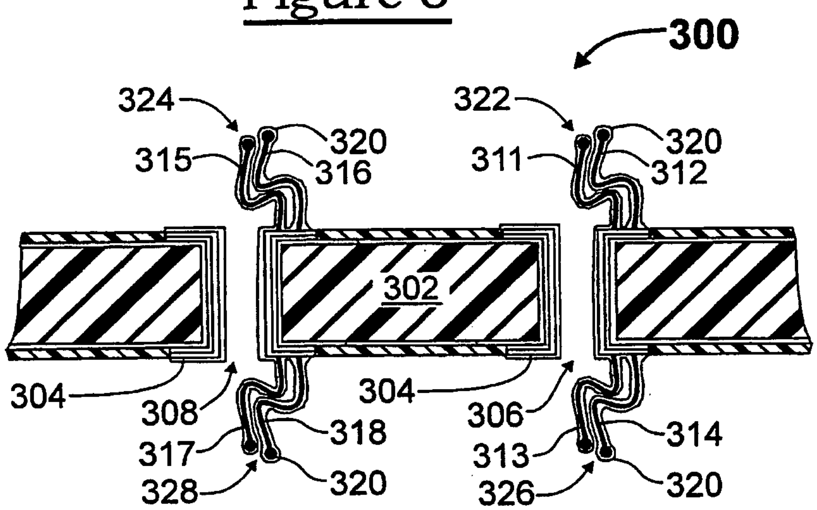

300
324
320
315
316
322
320
311
312
302
304
308
317
318
328
320
304
306
313
314
326
320

Figure 4

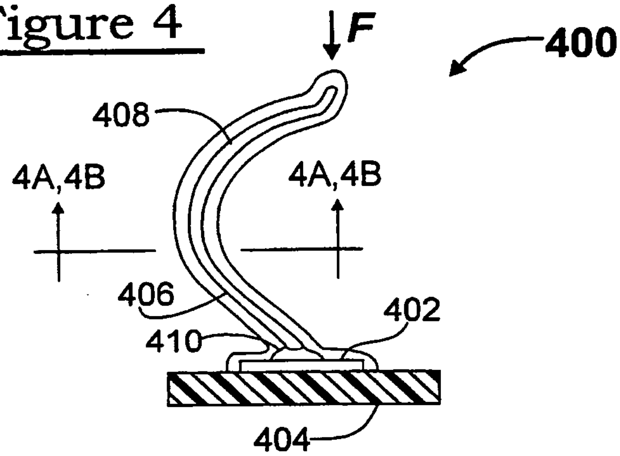


Figure 4A

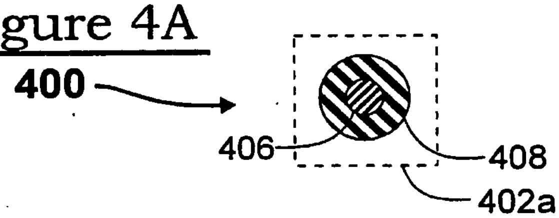


Figure 4B

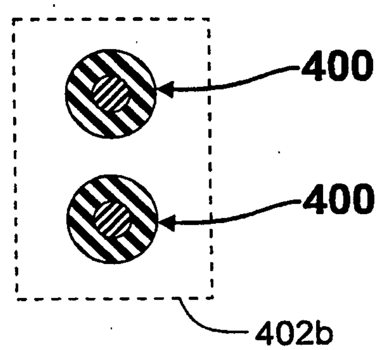


Figure 5

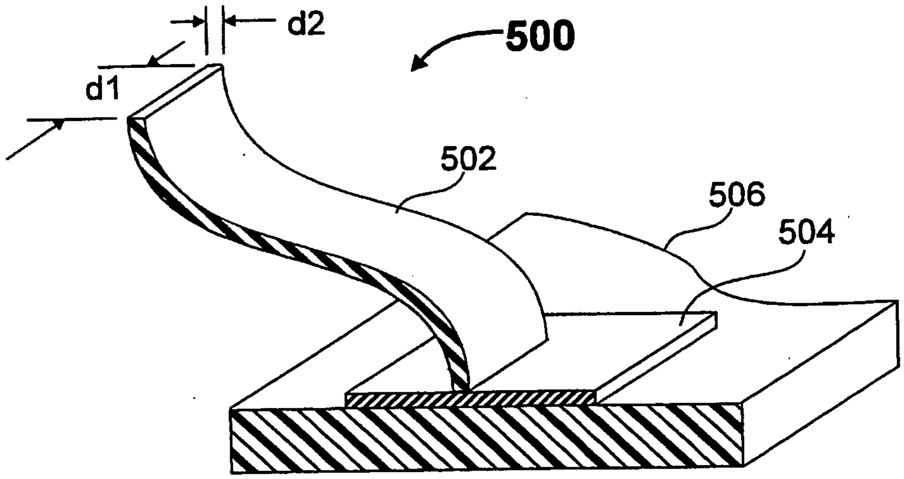


Figure 5A

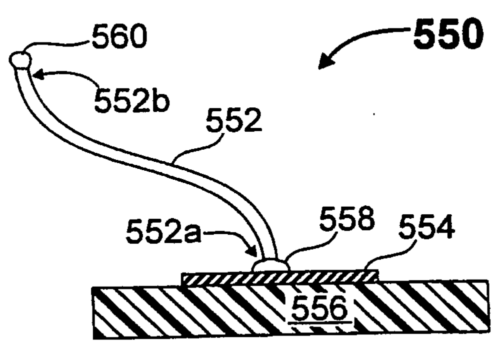


Figure 5B

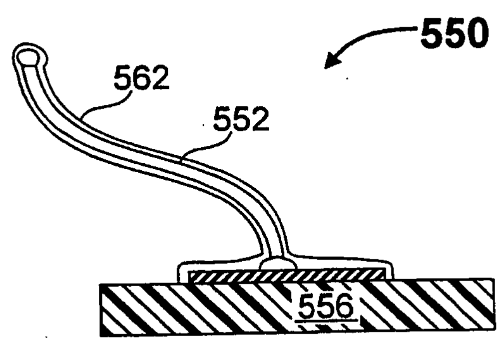


Figure 5C

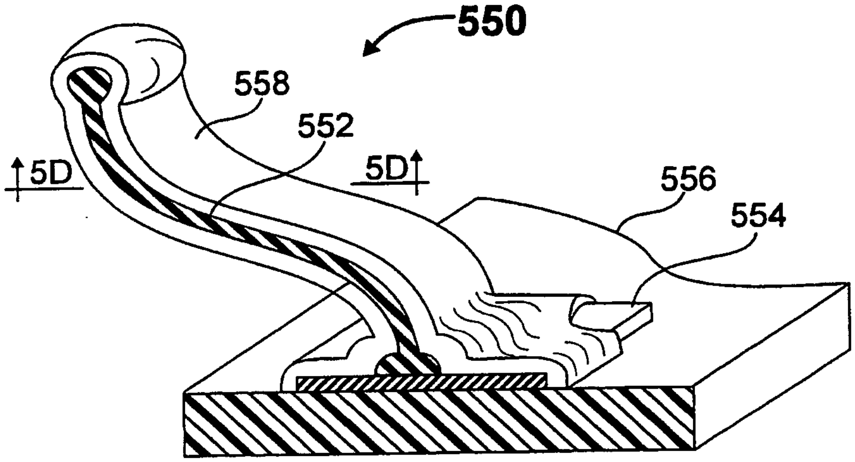


Figure 5D

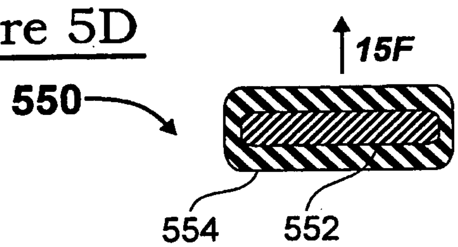


Figure 5E

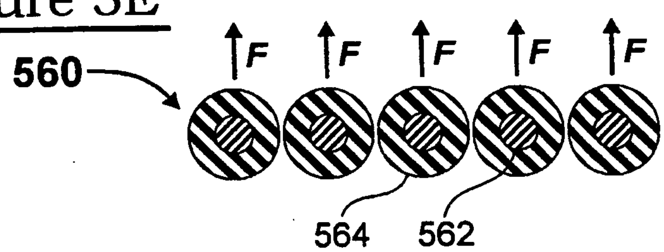


Figure 6A

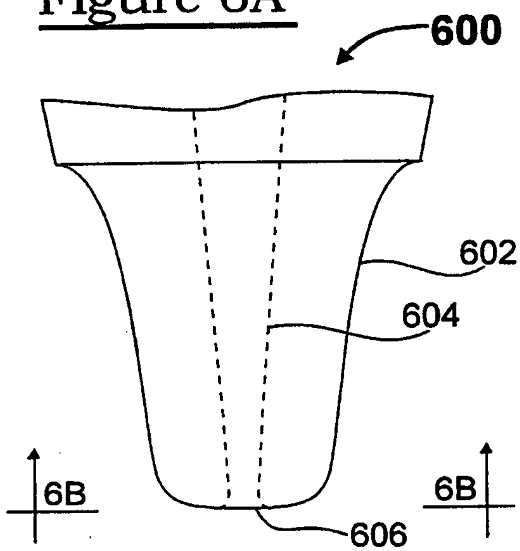


Figure 6B

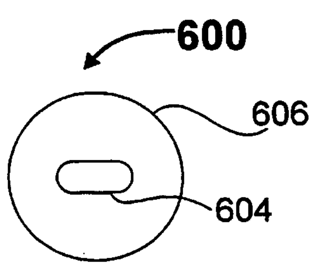


Figure 7A

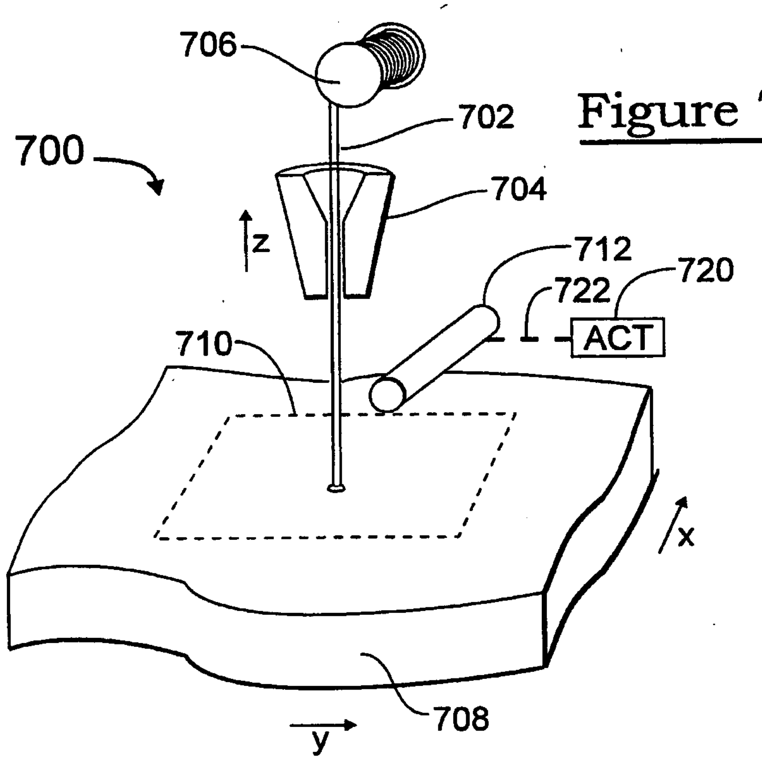


Figure 7B

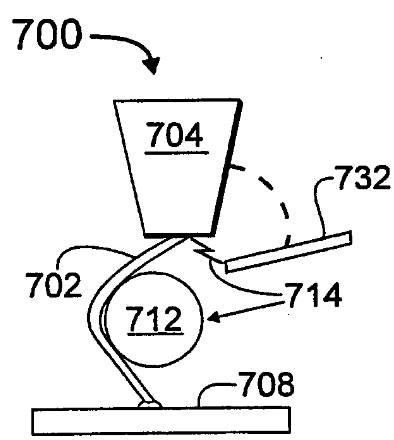
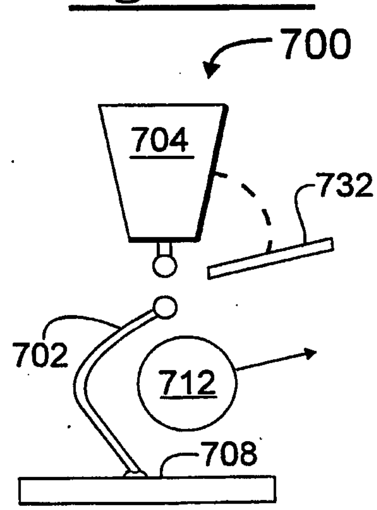


Figure 7C



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/08274

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B23K 31/02
US CL :228/4.5, 180.5; 29/842, 885; 439/66; 156/155
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 228/180.5, 4.5; 29/885, 842, 843; 439/66; 156/155

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,294,039 (PAI ET AL.) 15 MARCH 1994, SEE FIGURES 4A-7	11, 12, 14-18, 20, 21
A	US, A, 5,228,862 (BAUMBERGER ET AL.) 20 JULY 1993, SEE FIGUTES 3-5	36, 37
A, P	US, A, 5,476,211 (KHANDROS) 19 DECEMBER 1995, SEE FIGURES 1A-8, 14, 15	11-19, 22-35, 38-40
A	US, A, 2,429,222 (EHRHARDT ET AL.) 21 OCTOBER 1947, SEE FIGURES 1-3; COL. 1, LINE 46, THROUGH COL. 2, LINE 44	11, 13, 17, 19
A	US, A, 4,674,671 (FISTER ET AL.) 23 JUNE 1987, SEE FIGURES 2A-2G.	1-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 SEPTEMBER 1996	17 SEP 1996

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	for PAULA A. BRADLEY Sheila Veney Sheila Veney Paralegal Specialist Group 3200
Facsimile No. (703) 305-3230	Telephone No. (703) 308-1148

Form PCT/ISA/210 (second sheet)(July 1992)*